$$n'' = n + n' \quad \ldots\ldots (37)$$

$$r'' = \frac{n'}{n + n'} r' = \frac{n'}{n''} r' \quad \ldots\ldots (38)$$

$$p_v'' = \frac{n'}{n + n'} r' e = r'' e \quad \ldots\ldots (39)$$

$$p_a'' + p_v'' = 760 \quad \ldots\ldots (40)$$

$$p_a'' = 760 - p_v'' \quad \ldots\ldots (41)$$

10. Let n' volumes of air having the relative humidity r' be mixt with n'' volumes of air having the relative humidity r'', both being at the same temperature t and pressure 760 millimeters. If the total pressure continues the same, then the new volume and relative humidity are given by the following equations:

$$n''' = n' + n'' \quad \ldots\ldots (42)$$

$$r''' = \frac{n' r' + n'' r''}{n' + n''} \quad \ldots\ldots (43)$$

$$p_v''' = r''' e \quad \ldots\ldots (44)$$

$$b = p''' = p_a''' + p_v''' = 760 \quad \ldots\ldots (45)$$

$$p_a''' = 760 - p_v''' \quad \ldots\ldots (46)$$

Numerical examples.—1. If 1 cubic meter of dry air be mixt with 5 cubic meters of air having a relative humidity of 100 per cent, the mixture will consist of 6 cubic meters of moist air having a relative humidity of 83.33 per cent.

2. If 3 volumes of dry air be mixt with 5 volumes of air having a relative humidity of 50 per cent, the mixture will consist of 8 volumes of moist air having a relative humidity of 31.25 per cent.

3. If 3 volumes of air, relative humidity 25 per cent, be mixt with 5 volumes of air, relative humidity 75 per cent, the mixture will consist of 8 volumes of air having a relative humidity of 56.25 per cent.

11. Let n' volumes of air having relative humidity r' and total pressure p' be mixt with n'' volumes of air having relative humidity r'' and total pressure p''; let both have the same temperature t, and let the combined volumes be brought under pressure 760 millimeters and kept at the same temperature. The following equations will give the new volume and humidity:

$$p' = p_a' + p_v' \quad \ldots\ldots (47)$$

$$p_v' = r' e \quad \ldots\ldots (48)$$

$$p_a' = p' - r' e \quad \ldots\ldots (49)$$

$$p'' = p_a'' + p_v'' \quad \ldots\ldots (50)$$

$$p_v'' = r'' e \quad \ldots\ldots (51)$$

$$p_a'' = p'' - r'' e \quad \ldots\ldots (52)$$

$$n''' = \frac{n' p' + n'' p''}{760} \quad \ldots\ldots (53)$$

$$r''' = \frac{n' r' + n'' r''}{n'''} \quad \ldots\ldots (54)$$

$$p_v''' = r''' e \quad \ldots\ldots (55)$$

$$p_a''' = \frac{n' p_a' + n'' p_a''}{n'''} \quad \ldots\ldots (56)$$

$$760 = p_a''' + p_v''' \quad \ldots\ldots (57)$$

Numerical example.—If 2 volumes of air, relative humidity 50 per cent, under a pressure of 380 millimeters, be mixt with 5 volumes of air, relative humidity 25 per cent, under 500 millimeters pressure, the mixture under atmospheric pressure will consist of 4.29 volumes of moist air with a relative humidity of 52.45 per cent, under 760 millimeters.

THE GROWTH OF FOG IN UNSATURATED AIR.

By FRANK W. PROCTOR. Dated Fairhaven, Mass., November 8, 1906.

During the summers of 1901 and 1902 the writer made ter-daily observations of temperature, moisture, barometric pressure, wind direction and velocity, and the occurrence of fog at all hours, except during sleep, for the purpose of studying the origin of the summer fogs that are tolerably frequent on the south shore of Massachusetts, and that are seemingly capricious in their occurrence and endurance. Those observations, so far as they bore on the locus and the proximate cause of formation, and on the manner of advent, of the summer fogs of sufficient density to be called "fog" in the ordinary sense of the term, are discust in the MONTHLY WEATHER REVIEW for October, 1903.[1]

The observations (whose details will not be repeated here), also showed that over Buzzards Bay there existed almost continuously a haze which was deemed to be an aqueous haze, because it could usually be seen when the wind blew from the sea, because it graded so insensibly into the fogs ordinarily so-called that it was impossible to distinguish a thick haze from a light fog, and because the air was so completely cleared of the haze by anticyclones. This haze was observed with a wind from the south, and a relative humidity as low as 52 per cent determined with a sling psychrometer; and in the paper mentioned it was suggested that "the persistent aqueous haze over the bay with winds from seaward, seems to indicate not only that the saturation temperature is different for different kinds of nuclei, but also that under ordinary conditions the variety of suitable nuclei is large enough to make condensation a gradual process rather than a catastrophe at a certain critical vapor pressure".

The following summer a new series of observations was begun for the purpose of trying to correlate the growth of this haze with other weather conditions and changes. But it was found at the outset that as soon as the air was cleared of visible particles by a passing anticyclone, they formed again with astonishing rapidity under all conditions of weather by day and by night; and the observations were thereupon discontinued, with the only further result that it was seen that the haze, like other forms of fog, has a diurnal period, being denser at night when the temperature is lower.

The purpose of this article is to consider whether current theory and laboratory experiments furnish any confirmation or explanation of the apparently observed beginning of visible fog condensation in air far below normal saturation,[2] and its gradual growth with increasing vapor pressure into the ordinary, dense, atmospheric fog.

Long ago Lord Kelvin showed that a drop of pure water will evaporate in the presence of water vapor that is saturated with respect to a flat surface. This evaporation is due to the increased internal energy of the drop caused by the pressure of surface tension. The surface tension energy per unit area of a liquid surface is the same for flat and curved surfaces; but the tension of the curved surface around a drop of the liquid squeezes the drop and thus increases its internal energy. On drops of pure water of the ordinary sizes, owing to the changing curvature of the surface, the pressure due to surface tension increases as the radius of the drop diminishes. Since a drop of pure water will evaporate in a vapor just saturated, of course no drop can maintain its integrity unless the vapor has a degree of supersaturation precisely suited to the size of the drop. Any slight variation of the amount of moisture will make the drop either grow and fall as rain, or evaporate and disappear.

So there can be no gradual growth of fog from small vapor pressures. Any possible fog will appear suddenly when the appropriate supersaturation is reached, and it will necessarily be transitory. Practically, then, there can be no atmospheric fog of pure water droplets.

---

[1] A study of the summer fogs of Buzzards Bay, Vol. XXXI, p. 467.

[2] The terms "saturation" and "normal saturation" are used thruout in the sense of saturation for flat surfaces, or the degree of saturation in which the wet and dry bulbs of a sling psychrometer read alike. The terms "saturated" and "undersaturated" refer to this standard. The reasons for the distinction will appear.

Aitken showed that this obstacle to the condensation of water drops in saturated vapor is overcome by dust particles in the air, which serve to increase the radius of the drop and thereby give a flatter water surface; and C. T. R. Wilson discovered that the ionization of air also supplies nuclei that encourage condensation.

The presence of solid dust particles, tho furnishing a nucleus that permits condensation at a lower vapor pressure than in dust-free vapor, does not alter the condition of unstable equilibrium that characterizes the ideal droplet of pure water, and apparently, therefore, solid dust particles can not make a stable fog possible.

The theoretical behavior of a drop of water that carries a charge of electricity is curious and interesting. J. J. Thomson has shown that the presence of an electric charge on a drop of water tends to prevent evaporation, and when the drop is very small will neutralize the effect of the surface-tension pressure, which tends to promote evaporation. With the charge deduced from an artificial laboratory cloud, he computed that such a drop has a radius 10^{-8} cm.—not much larger than the molecules of water.[3]

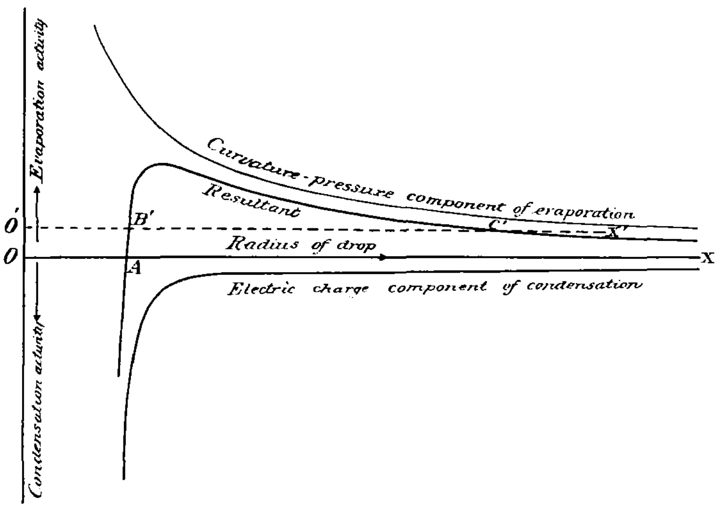

FIG. 1.—The effects of surface curvature and electric charge upon the condensation and evaporation of drops of water.

The accompanying diagram, fig. 1, which is inserted solely for illustrative purposes, not to indicate actual values, shows the general character of the separate and combined effects of an electric charge and the pressure of curvature due to surface tension, on the condensation and evaporation of drops of water of variable size, in vapor just saturated for a flat surface, temperature being constant, on the assumption that the surface tension of uncharged drops of pure water per unit area is constant for all sizes of droplets, and that none of the charge escapes. In this figure the effect of the charge has been enormously exaggerated in order to get a suitable curve for plotting, but in general it follows the equations given by C. T. R. Wilson, Smithsonian Report 1904, p. 198.

The pressure of the external saturated vapor just offsets the vapor pressure at a flat, uncharged surface. These two evaporation and condensation factors thus just balance each other and they may therefore be ignored in tracing the opposing effects of the charge (lower curve) and of the surface curvature (upper curve) upon condensation and evaporation at the surface of the drops. The middle curve, which is the resultant of the other two curves, shows the effective excess of evaporation or condensation. The portion of this curve lying above the axis $O\,X$ indicates evaporation, the part below indicates condensation. The intersection of the curve with $O\,X$ at A indicates the size of the charged drop at whose surface the vapor pressure is in equilibrium with the external saturated vapor. For drops of varying sizes, the curves show the changing conditions with respect to these evaporation and condensation factors, and with respect to their resultants.

Starting at the right of the diagram with a saturated vapor for the flat surface and a large, charged drop with small curvature, let the contending effects of the charge and of the pressure due to surface tension be followed as the radius of the drop is supposed to be arbitrarily and gradually diminished, the temperature and vapor pressure remaining constant. At the start the charge reduces the internal energy of the liquid, but not sufficiently to overcome the increase of internal energy due to curvature pressure, so that now the drop would evaporate in the vapor just saturated for a flat, uncharged surface. For drops successively smaller the surface-tension pressure (the evaporation factor) by reason of the shortening radius of curvature, will increase at a slowly growing rate. Owing to the concentration of the constant charge on the smaller surface, the effect of the charge (the condensation factor) will also increase. Its rate of growth will be an increasing rate, which at first will be slower than the rate of growth of the evaporation factor; but finally with smaller and smaller drops the rate of growth of the condensation factor will become the larger of the two.

It accordingly results, as the radius of the drop is supposed to be reduced, that for a while, as the drop diminishes in size, the evaporation factor will predominate and will grow faster than the condensation factor; but eventually its excess of influence will reach a maximum value, owing to the increasing rate of growth of the efficiency of the charge, and thenceforth this excess of evaporation efficiency will gradually decline as the influence of the charge continues to increase at a faster and faster rate, until both influences become equal. This is a critical point in the size of the drop. The drop is in equilibrium with its vapor and the equilibrium is stable, for it is seen that smaller drops will condense and grow to this critical size, because from this point downward, with shorter radii, the condensation factor will be dominant. Larger drops will evaporate down to this critical size by reason of the greater influence of the surface-tension pressure. This size is stable for the given vapor pressure only, viz, saturation for a flat surface. For this vapor pressure there can be no gradual growth of drops of larger radius than A, a very small droplet; and consequently there can be no rain unless raindrops can in some way be created at once of full size.

For other vapor pressures the critical size of the drops will have other values, depending upon the amount of the vapor pressure. For higher pressures stable-equilibrium size will be larger, for lower pressures stable-equilibrium size will be smaller. Any increase of vapor pressure will augment the condensation activity and the resultant curve will thereby be lowered with respect to the axis $O\,X$, or what comes to the same thing, $O\,X$ will be raised as indicated by the broken line $O'\,X'$. For lower vapor pressures the condensation activity will be diminished and the resultant curve will be raised or the axis lowered.

If the axis $O\,X$ be raised to suit a higher vapor pressure, as is indicated by the broken line, it will cut the resultant curve in two places, and the intersection at C' indicates a second critical size of the drop. It is again in equilibrium with the surrounding vapor. The drop will neither grow by condensation nor diminish by evaporation as long as the vapor remains at this pressure. But the equilibrium is unstable—any slight variation of the vapor pressure will destroy it; larger drops will grow continuously until precipitated, while smaller drops will evaporate down to stable equilibrium size at B'.

If the vapor pressure be further increased the dotted axis

[3] The discharge of electricity through gases, p. 15.

will cut the resultant curve still higher. The region of no growth between B' and C' will be shortened and the region of potential growth will be extended. If the vapor pressure continues to increase, the points of intersection will approach each other and finally meet at the highest point of the resultant curve. Henceforth drops of all sizes will be unstable and will grow until precipitated.

Apparently reduction of the size of the drop can go on without limit, the drop being successively in stable equilibrium with smaller and smaller vapor pressures until the range of molecular attraction is reached. There the surface tension becomes smaller and below this point the equilibrium will be unstable. There will be no further increase of the evaporating force with diminishing radius of the drop; and in any vapor pressure drops of smaller size will grow up to the size where molecular attraction has full range.

At some point in this descending scale used for illustration the drop becomes so small as to be invisible, viz, when it is too small to scatter the violet rays of light. Whether this point will be reached depends upon the amount of the electric charge. As has been seen, the smaller the charge the smaller the drop must be in order to be in equilibrium with a given vapor pressure. If the charge is the ionic charge there is a limit to its amount[4], and it may be so small that when equilibrium for flat-surface saturation is reached the drops are too small to make a visible haze.

Tho drops rendered stable by electric charge in vapor just saturated for a flat surface, and of course also in unsaturated vapor, may be too small to make a visible haze, any such minute, stable, invisible droplets will serve as nuclei for condensation, and will grow whenever the vapor pressure is increased by any small increment whatsoever.

If the charge on a drop is sufficiently increased, stable equilibrium will be reached in unsaturated vapor with drops large enough to be visible.[5] Dissolved matter in a drop reduces the internal energy of the drop, and thus has a similar effect to that of an electric charge in promoting condensation. In the case of drops of very dilute solutions the evaporating influence of the pressure of curvature is the stronger, but as a drop becomes more concentrated by evaporation to a smaller diameter, the influence of the dissolved substance grows faster than the effect of the surface-tension pressure. Eventually the two influences become equal, and stable equilibrium is reached for the given vapor pressure. For smaller drops and more concentrated solutions condensation will take place. Prof. Carl Barus has constructed the curve showing these relations.[6]

There is no such limit to the amount of matter that may be in solution in a drop under ordinary atmospheric conditions, as there is to the amount of the electric charge on a drop; and in strong solutions the drops that attain stable equilibrium are larger than those that carry the ionic charge of electricity. If the solution be sufficiently concentrated, the stable size of drops will be reached (in the descending scale used for illustration) while the drops are large enough to make a cloud that is readily visible. For varying humidities the solution must increase in concentration as the vapor pressure diminishes in order that the drops may be visible. In the formation and growth of atmospheric fog condensation is probably promoted by the joint influence of dissolved substances and ionization.

Let the behavior of a drop be considered as it grows in the atmosphere from small beginnings in a low vapor pressure.

There is always some vapor in the atmosphere, and minute drops having an electric charge, and drops of solutions, both charged and uncharged, never completely evaporate owing to the effect of the charge, the density of the solution, and the low pressure of the vapor. Such droplets, according to Barus, are "nuclei" of condensation.[7] As seen above, their size depends upon the vapor pressure and upon the intensity of the charge or the amount of the dissolved substance. Drops having a small amount of matter in solution will have to evaporate to a very small size in order to become sufficiently concentrated to resist further evaporation. Those with larger amounts of the dissolved substance will make larger drops sufficiently concentrated to be in equilibrium for any given vapor pressure: so at any time there are in the atmosphere stable drops of various sizes, depending upon the amount of the substances in solution. The maximum size of drops that can be in stable equilibrium in vapor much below normal saturation will thus be limited only by the amount of foreign matter that can be captured by a drop. At low atmospheric vapor pressures the fog or haze will be tenuous owing to the small number of the particles, and it may be invisible because the particles are too few and too small to scatter even the violet rays of light.

If now the vapor pressure increases, the drops will all grow by condensation until the effect of the pressure of curvature again just balances the diminishing effect of condensation due to dilution of the solution. With sufficient increase of vapor pressure, the nuclei will grow in size and number enough to make the air turbid, and thus there will be a gradually increasing density of the fog-haze, as the vapor pressure increases. In its early stage the haze will be bluish or smoky, because most of the particles are large enough to scatter only short waves of violet light. The most concentrated drops sooner arrive by growth at the stage of unstable equilibrium, where the evaporation factor of curvature-pressure can no longer offset the condensation factor due to the dissolved substance and the charge; and such drops continue to grow to precipitation size without any further increase of vapor pressure, and fall out of the fog cloud. Probably they fall so slowly as not to be ordinarily noticed. By this sifting out of the unstable drops the fog cloud remains composed mainly of the stable drops, and has a good degree of permanency as long as the increase of vapor pressure is tolerably gradual.

With solutions the question of stability or saturation in any vapor pressure is therefore apparently only a question of the density of the solution, in addition to the small charge, if any, due to ionization.

Thus there seems to be a sufficient basis for explaining the observed haze on the hypothesis that it is in fact nascent fog, perceptible in unsaturated air, provided there is reason to believe that there is enough soluble material in the air to give the droplets the required concentration of solution. There is probably no difficulty on this score. More or less of the solid dust particles in the air contain soluble material. The spray from the splashing of the sea waves, and particularly from the breaking of the waves in shallow water and in the surf, is continually supplying to the air drops of water containing various salts, which evaporate down to the stable size for the existing vapor pressure, and remain stable and persistent for long periods, becoming larger and smaller as the vapor pres-

[4] According to the English investigators of cloudy condensation, when there is a charge on a fog droplet it is the atomic charge and so is constant in amount. But Barus has found, on increasing the intensity of ionization of moist air by bringing the ionizing agent nearer the fog chamber, or by a longer exposure, that not only the number of the nuclei increases but also their size. He is of the opinion that the effect of ionization of moist air is to unite the minute permanent nuclei of the air into larger nuclei. Science, February 17, 1905, p. 275; April 14, 1905, p. 562.

The formation of such larger, stable nuclei by intense ionization suggests the possibility of the existence of a charge on a nucleus droplet larger than the charge for a gaseous ion.

[5] Fog droplets are usually too small to be visible as individual objects. They become perceptible when they are sufficiently large and numerous to scatter enough rays of light to make a visible haze.

[6] The structure of the nucleus, p. 135.

[7] Ibid., pp. 132, 135.

sure fluctuates; and these nuclei or fundamental droplets undoubtedly often coalesce and thus increase the amount of substance in solution in such drops, so that they are of various degrees of salinity. It will also be seen later that there are other sources from which fog drops obtain soluble material.

Artificial fogs have been studied for a long time in laboratories, by means of moist air in chambers in which the air can be suddenly cooled by partial exhaustion, for the purpose of discovering the relations of foreign nuclei to aqueous condensation, notably by Tyndall, Aitken, and C. T. R. Wilson, in England, by Barus, in America, and by other eminent physicists in Europe. In nearly all of the experiments it has been found necessary to expand the air 1.25 times its original volume in order to produce visible condensation. This expansion corresponded to about a fourfold supersaturation. Accordingly in the tolerably abundant literature on the subject, the condensation of the supersaturated aqueous vapor both in the laboratory and in the free atmosphere is often discust tho little mention is made of condensation in undersaturated vapor.

During some lectures at Princeton University in 1896,[8] J. J. Thomson said: "Mr. Townsend has discovered that electrified gas possesses the remarkable property of producing a fog when admitted into a vessel containing aquous vapor. This fog is produced even tho the vessel is far from being saturated with moisture, and does not require any lowering of temperature such as would be produced by the sudden expansion of the gas in the vessel in which the fog is produced".

Townsend himself says: "When these charged gases [oxygen and hydrogen] get into the atmosphere of the room they condense the moisture and form a stable cloud in an unsaturated atmosphere".[9]

A cloud made by bubbling the charged oxygen from a sulphuric acid electrolyte thru water, and collected in a glass vessel, was dense enough to show subsidence of the cloud by photographs taken three minutes apart.[10]

According to C. T. R. Wilson, later experiments by H. A. Wilson show that it is probable that the condensation of these fogs was not due to the charge but to the presence of some substance in solution.[11]

To whatever cause the fog clouds were due, the important point to be noted here is that visible fog clouds were formed in ordinary, unsaturated air. The gases were formed and charged by the decomposition of dilute sulphuric acid and caustic potash solutions, by an electric current. On being bubbled thru water, or even on escaping into the moist air of the room, a cloud was formed.

C. T. R. Wilson found that under suitable illumination, visible fog was produced in laboratory exhaustion chambers, under the influence of strong ultraviolet light, in unsaturated air.[12] The source of this light was sparks produced between zinc terminals by an induction coil. The light entered the exhaustion chamber thru a quartz lens, which concentrated the rays; and it was therefore much stronger in ultraviolet rays than sunlight that has past thru the atmosphere, which scatters and filters out these rays in large degree. With weak ultraviolet rays, and with a concentrated beam of sunlight, no fog was visible in undersaturated air.[13]

Professor Barus has especially investigated the condensation of efficiency of nuclei produced by the violent agitation of solutions in a closed vessel from which the air could be partially exhausted, and the remaining air and vapor be thereby cooled. In sundry experiments the normal barometric pressure was reduced by 4 to 76 centimeters in order to produce visible fog;[14] and Professor Barus makes no mention of seeing fogs in undersaturated vapor, tho in a few instances "spontaneous condensation" in air, just saturated and not expanded, are recorded.[15] He found that the number and size of the "shaken" nuclei increase with increasing concentration of the solution in the drop.[16]

According to C. T. R. Wilson, the effect of the action of ultraviolet light upon moist air is to oxygenate the water and form hydrogen peroxide, which is soluble in the drop; and the amount of peroxide thus formed depends upon the intensity of the light and the time of action.[17] And Barus suggests "that such chemically powerful agencies as the X rays or Becquerel rays, or ultraviolet light, or the electric glow, etc., on being past thru a saturated vapor, produce in that vapor a new chemical synthesis, * * * soluble in the liquid from which the vapor arises".[18] These are the additional sources of soluble foreign matter above referred to, by means of which condensation may be expected in undersaturated water vapor.

Both of these physicists find that atmospheric nuclei usually carry an electric charge tho no ionizing agent be used in the experiments, and they attribute the charge to self-ionization. The general occurrence of radio-active matter in the air and on the surface of the earth, found by Rutherford and others, would perhaps account for this moderate ionization.

No intimation has been found in the papers of either Wilson or Barus that condensation does in fact occur in the undersaturated, free atmosphere under normal conditions; and there is much in the papers of Wilson to indicate the contrary opinion. For example, he makes the amount of supersaturation required for condensation in the laboratory a basis for the classification of different kinds of nuclei; and running all thru his principal papers on the subject there seems to be a tacit assumption that the results obtained in the laboratory hold true for the free air outside. The following are typical statements:

"They [ions] do not act as centers of condensation unless the vapor is about 4.2 times as dense as that in equilibrium over a flat surface of water at the same temperature".[19]

"There is, I think, no evidence that the ions alone, in the absence of other influences, ever act as centers of condensation unless the above-mentioned comparatively great degree of supersaturation (approximately fourfold) being exceeded".[20]

"The nuclei which, when they are only exposed to very weak [artificial] ultraviolet light, do not grow beyond the stage at which a fourfold supersaturation is required to make condensation take place upon them, etc".[21]

Perhaps these unqualified expressions refer only to laboratory fogs, but it is nowhere explicitly so stated.

Wilson also experimented with sunlight as a cause of condensation in the laboratory fog chambers. A quartz window was used so as not to exclude the ultraviolet rays, and the window was lens-shaped so as to concentrate the beam and give increased nucleating and illuminating effect to the rays. No condensation was produced in either saturated or undersaturated, filtered air.

On the other hand, there is much in Wilson's papers to warrant the inference that condensation of undersaturated vapor in the free air is possible. In general he seems to use the terms "nuclei" and "fog particles" as interchangeable, and as differing only in degree. In a paper presented at the International Electrical Congress at St. Louis in 1904,[22] Wilson says

[8] The discharge of electricity through gases, p. 11.
[9] Camb. Phil. Soc. Proceed., vol. 9, p. 249.
[10] Ibid., p. 351.
[11] Phil. Trans. Roy. Soc. Lond., 192, p. 452.
[12] Phil. Trans., 192, pp. 419, 423.
[13] Phil. Trans., 192, p. 430.

[14] The structure of the nucleus, pp. 33 *et seq.*
[15] Ibid., p. 33.
[16] Ibid., p. 132.
[17] Phil. Trans., p. 192, pp. 428, 450.
[18] The structure of the nucleus, p. 135.
[19] Phil. Trans., 192, p. 451.
[20] Ibid., p. 453.
[21] Ibid., p. 420.
[22] Reprinted in Smithsonian Institution Report, 1904, p. 195.

in speaking of the "dust" particles of the atmosphere: "It would be difficult to find a means of determining whether they consist of solid particles or of minute drops of liquid".

Elsewhere he says: "For we may suppose such nuclei [charged nuclei] to be very small drops of water, which are able to persist in spite of their small size, because the effect of the curvature of the surface in raising the equilibrium vapor pressure is balanced by the opposite effect produced by the drop either being charged with electricity or containing some substance in solution. An increase in the charge of electricity, or of the quantity of dissolved substance, either of which would increase the efficiency of the drop as a condensation nucleus, would also result in an immediate increase in the size of the nucleus necessary for equilibrium".[23]

"The cloud or nuclei-producing effect of ultraviolet light rays obviously has bearings on other meteorological phenomena. The nuclei which enable clouds to form may in many cases arise from this source. The upper clouds may especially owe their formation in this way to the action of sunlight. It is possible too, that owing to the action of the ultraviolet rays, sunlight may cause clouds to persist in undersaturated air".[24]

"Altho in these sunlight experiments no nuclei, requiring only slight supersaturation to make condensation take place on them, have been produced, they do not absolutely prove that such nuclei may not be formed by sunlight even in the lower layers of the atmosphere. For it is quite possible that the disappearance of the nuclei produced by weak ultraviolet light when they are left to themselves, is entirely due to the fact that they very quickly reach the walls of the vessel by diffusion on account of their small size".[25]

Prof. J. S. Townsend said in one of his papers: "The clouds which are formed by electrified gases are perfectly stable even in an unsaturated atmosphere, and in this respect bear a close resemblance to atmospheric clouds".[26]

Tho there is little or no definite statement in the papers above mentioned concerning the probability of the condensation of fog under natural conditions in the lower atmosphere at relative humidities below 100 per cent for flat surfaces, the general tenor of these papers seems to warrant an inference that such may be the fact.

Barus points out that equilibrium vapor pressure is variable for drops of different sizes and for drops of the same size having different amounts of foreign matter in solution;[27] and Wilson shows that in theory this is true of drops having an electric charge as well as of drops containing matter in solution.[28]

Both of these physicists regard minute water droplets as "dust" nuclei, normally present in the atmosphere at all ordinary degrees of humidity; and since these minute water drops grow to precipitation size in the free air when the increase of vapor pressure is gradual, it seems to follow necessarily that condensation occurs under all these varying conditions of undersaturation for flat surfaces.

If, in fact, fog does grow gradually in the atmosphere, beginning to be visible with relative humidities as low as 52 per cent, as the observations under discussion apparently show, the question at once arises why it has not been seen in unsaturated air in the laboratory fog chambers, save in gases formed by electrolysis, and in case of the action of stronger ultraviolet light than is found in the lower atmosphere; and particularly why it has not been seen in the fog chambers of Professor Barus, in undersaturated air containing highly concentrated solution nuclei.

[23] Phil. Trans., 192, p. 404.
[24] Ibid., p. 431.
[25] Phil. Trans., 192, p. 431.
[26] Cambridge Phil. Soc. Proceed., vol. 9, p. 257 (1897).
[27] The structure of the nucleus, p. 132.
[28] St. Louis address.

Two reasons suggest themselves: (1) In those experiments the air was filtered thru closely packed cotton, and this would remove nuclei or droplets of any considerable size, which otherwise perhaps might have been seen in unsaturated air if they were numerous enough. (2) But the small size of the fog chambers gives a more probable reason why laboratory fogs have not been seen in unsaturated air. These chambers do not contain enough particles of the tenuous fogs that condense in the unsaturated outdoor air to make a visible haze. Wilson's fog chambers were tubes of 1.6 centimeter to 4 centimeters diameter, which in observing fogs were looked at transversely. It is not surprising that fog particles so far apart that an air column 11 miles[29] long is necessary to contain a sufficient number of particles in the line of sight, to scatter and reflect enough light to make a barely visible faint haze, could not do this in a column only five-eighths of an inch to one and one-half inches long. It might require several such diminutive columns to cover the distance between two fog particles. And furthermore, as Wilson points out, there is little time for fog particles to grow in such small tubes before they would reach the walls by diffusion and be lost.

In the experiments of Professor Barus the conditions were somewhat different. His fog chambers were globular and larger, from 23 to 33 centimeters in diameter, but yet very small in cross section as compared with the 11-mile air section of the outdoor observations in question. Furthermore his fog particles were not observed directly, but by means of the diffraction coronas produced by a beam of light upon the droplets—that is to say, the expansions were such as were required to produce the coronas.

He states that the particles must be numerous enough to lie not more than two millimeters apart, in order to make normal coronas in these chambers.

Such incipient fog hazes as were seen by me to form and grow over Buzzards Bay in undersaturated, outdoor air, are too tenuous to cause coronas in such small fog chambers—the particles are too far apart. Barus specifically calls attention to the fact that in his experiments the amount of expansion required for visible condensation varies with different apparatus, and he usually gives the results of a series of experiments as applicable only to the apparatus used therein.

Apparently then, there is not only sufficient plausible theory to explain the observed phenomena, but also little or nothing in the results of laboratory experiments inconsistent with the outdoor observations.

To sum up, from the point of view suggested by the observations under discussion, saturation of atmospheric water vapor is a relative condition, condensation beginning upon certain nuclei as soon as there is any vapor at all in the air, and progressing gradually either with growing vapor pressure, or with other favoring conditions such as concentration of dissolved matter in the nuclei, electric charge thereon, or change of shape of the condensing surface, in addition to the suitable conditions of temperature that alone are commonly considered to be the controlling factor for any given vapor pressure. Thus water vapor is always saturated for certain nuclei that are usually found in the atmosphere.

Fog then is normally present in the lower atmosphere, at least over and near the sea. It is often invisible, the visibility depending upon the size of the droplets (nuclei) and their number per unit volume of space. It is more often either unnoticed or not recognized as fog, because it usually has the aspect of a thin, smoky haze.

This view affords a good explanation of the fact that a sling psychrometer rarely indicates saturation, even in dense fogs.

[29] This is the distance of the hills on the farther side of Buzzards Bay which served as a background, by means of which the existence in the air over the bay of visible haze, and its relative density, were observed by me.

In such cases the vapor is not saturated with respect to the covering of the wet bulb, altho it is supersaturated with respect to the nuclei or smaller drops of the preceding stages of fog growth.

There seems to be no reason to discriminate between fog and higher clouds in respect to the general aspects of condensation, evaporation, and stable existence in unsaturated air,[30] tho the distribution of the various kinds of nuclei probably varies with height.

It is suggestive to note here that at Blue Hill it has been found that raindrops are of all sizes from those of the finest mist to the largest drops; and it has been found necessary to adopt an arbitrary definition of what should be recorded as rain.

Those observations combined with the observations under discussion, therefore, tend to show a regular gradation in the size of water particles from the smallest, invisible condensation nuclei up to the largest raindrop.

[30] It appears from the observations made in Germany from manned balloons that even the vapor of dense clouds is rarely saturated with respect to the psychrometer. In 61 ascents discust by Dr. Reinhard Süring, in Wissenschaftliche Luftfahrten, Bd. 3, S. 133 *et seq.*, clouds were past thru by the balloons 43 times, and 100 per cent relative humidity was found in 6 clouds only.

CLIMATOLOGICAL SUMMARY.

By Mr. JAMES BERRY, Chief of the Climatological Division.

TEMPERATURE AND PRECIPITATION BY SECTIONS, JANUARY, 1907.

In the following table are given, for the various sections of the Climatological Service of the Weather Bureau, the average temperature and rainfall, the stations reporting the highest and lowest temperatures with dates of occurrence, the stations reporting greatest and least monthly precipitation, and other data, as indicated by the several headings.

The mean temperatures for each section, the highest and lowest temperatures, the average precipitation, and the greatest and least monthly amounts are found by using all trustworthy records available.

The mean departures from normal temperature and precipitation are based only on records from stations that have ten or more years of observation. Of course the number of such records is smaller than the total number of stations.

Section.	Temperature—in degrees Fahrenheit.								Precipitation—in inches and hundredths.					
	Section average.	Departure from the normal.	Monthly extremes.						Section average.	Departure from the normal.	Greatest monthly.		Least monthly.	
			Station.	Highest.	Date.	Station.	Lowest.	Date.			Station.	Amount.	Station.	Amount.
Alabama	54.4	+10.2	Pushmataha Wetumpka	84 84	15 9	Riverton	13	28	2.20	−2.56	Dadeville	4.00	Letohatchie	1.03
Arizona	44.5	+ 1.2	Aztec Yuma	78 78	27 28	Flagstaff (*a*)	−10	2	2.66	+1.16	Huachuca Reservoir	15.96	Parker	0.13
Arkansas	49.2	+ 9.7	Pine Bluff	82	7	Pond	− 8	26	5.80	+1.38	Malvern	11.80	Montrose	1.95
California	43.9	− 1.0	Craftonville	90	22	Tamarack	−14	17	7.46	+2.26	Helen Mine	27.21	Mammoth Tank	0.00
Colorado	27.9	+ 4.4	Lamar	76	4	Antelope Springs	−34	3	0.81	−0.12	Corona	5.60	2 stations	0.00
Florida	63.4	+ 5.3	Clermont Orange City	88 88	2 20	Molino	25	22, 23	0.80	−2.24	Pensacola	4.05	New Smyrna	0.00
Georgia	54.4	+ 9.9	Statesboro Valdosta	84 84	14 14	Diamond	17	28	1.29	−2.52	Eatonton	3.06	Valdosta	0.10
Hawaii	70.0†	......	Olaa Mill, Hawaii	90	23	Volcano House, Haw	49	22, 23	12.07‡	......	Olokele Ditch, Kauai	34.04	Kalopa, Hawaii	1.10
Idaho	22.6	− 3.9	Hotspring	61	29	Chesterfield	−32	16	2.64	+0.84	Landore	8.28	Salmon	0.58
Illinois	31.1	+ 4.8	Tilden	77	19	Zion	−11	26	5.69	+3.22	Equality	10.90	Lanark	2.67
Indiana	34.0	+ 6.7	Farmersburg	77	19	Auburn	− 7	23	6.96	+4.27	Marengo	11.83	Lima	2.94
Iowa	18.8	− 1.0	Keokuk	68	7	Forest City Inwood	−22 −22	30 30	1.52	+0.57	Burlington	5.30	Atlantic	0.20
Kansas	31.2	+ 1.8	3 stations	75	6, 7	Ellsworth	− 7	26	2.38	+1.53	Yates Center	7.16	Coolidge	0.05
Kentucky	43.2	+ 8.6	Loretto	83	20	Williamsburg	−11	29	8.02	+4.02	Owensboro	12.73	Williamsburg	1.62
Louisiana	60.7	+10.8	Lafayette	89	7, 15	Plain Dealing	20	27	1.83	−2.69	Sugartown	4.45	Robeline	0.55
Maryland and Delaware	35.8	+ 4.1	Milford, Del	77	7, 8	Oakland, Md	−19	23	3.08	+0.04	Deer Park, Md	7.00	Millsboro, Del	1.28
Michigan	20.6	+ 0 5	Dundee	69	19, 20	Humboldt	−42	30	3.42	+1.27	Vassar	6.80	Humboldt	0.65
Minnesota	3.8	− 4.8	New Richmond St. Charles	44 44	5 6	Bagley	−45	22	1.17	+0.47	Mount Iron	2.70	Pipestone	0.14
Mississippi	56.0	+ 9.8	Greenwood Leakesville	83 83	14 15	Hernando Holly Springs	16 16	26, 28 27	2.41	−3.06	Walnut Grove	6.58	Fayette	0.15
Missouri	34.3	+ 3.8	Caruthersville	76	18	Unionville	− 5	26	5.10	+2.85	Versailles	9.45	Conception	1.26
Montana	6.7	−12.7	3 stations	55	3 dates	Chinook	−45	14	1.60	+0.77	Saltese	6.79	Graham	0.22
Nebraska	19.9	− 1.2	Imperial	64	23	Agate	−24	3	0.50	−0.10	Wisner	2.14	Loup	T.
Nevada	27.0	− 1.9	Wadsworth	73	31	Squaw Valley	−28	16	2.22	+0.93	Palmetto	8.90	Carson Dam	0.06
New England*	20.5	− 1.1	3 stations	65	7	Oquossoc, Me	−45	17	2.81	−0.85	*Danielson, Conn*	5.62	Greenville, Me	0.98
New Jersey	31.8	+ 1.8	Cape May C. H	71	7	Layton	−19	27	3.50	−0.30	Chatham	5.80	Cape May C. H	1.93
New Mexico	38.0	+ 5.6	Monument	77	22	Dulce	−27	3	1.19	+0.68	Cloudcroft	6.32	Valley	T.
New York	22.5	+ 0.9	Otto	74	20	Indian Lake North Lake	−35 −35	24 24	2.94	+0.08	North Lake	5.28	Harkness	0.99
North Carolina	48.1	+ 8.2	Southern Pines	84	15	Saxon	4	28	0.77	−3.02	Southport	2.35	2 stations	0.05
North Dakota	−6.2	−13.6	Willow City	48	1	Willow City	−45	14	1.40	+0.81	Lakota	3.94	Berthold Agency	0.30
Ohio	32.2	+ 4.4	Ironton	75	3	Green Hill	−23	27	6.11	+3.41	Green	9.55	Bowling Green	3.43
Oklahoma and Indian Territories.	43.2	+ 5.8	Durant, Ind. T S. McAlester, Ind. T.	80 80	18 13	*Fort Reno, Okla*	8	27	2.63	+1.40	Calvin, Ind. T	5.09	Kenton, Okla	0.27
Oregon	30.6	− 4.4	Bay City	71	23	Prineville	−20	15	6.64	+0.81	Port Orford	19.56	Riverside	0.60
Pennsylvania	30.0	+ 2.4	Irwin	75	4	Pocono Lake Wellsboro	−23 −23	27 24	4.36	+1.12	Confluence	9.69	Center Hall	2.14
Porto Rico	70.9	......	Anasco	97	27	Cayey	46	28	2.16	......	Barros	7.67	*Juana Diaz*	0.00
South Carolina	53.4	+ 7.7	Conway Florence	89 89	13 13	Darlington Dillon	18 18	29 29	0.71	−2.88	Georgetown	1.91	2 stations	T.
South Dakota	6 4	− 8.9	Fort Meade	60	23	Kidder	−33	15	1.17	+0.79	Leola	2.95	Howard	0.25
Tennessee	48.2	+10.5	3 stations	79	18	Springdale	− 5	28	2.91	−1.52	Union City	8.20	McGhee	0.45
Texas	55.5	+ 8.6	Eagle Pass	92	13	Henrietta	10	26	1.04	−1.20	Arthur City	4.10	5 stations	0.00
Utah	28.0	+ 2.1	3 stations	66	26, 28	Ranch Tropic	−20 −20	2 17	2.30	+1.33	Park City	10.96	2 stations	0.00
Virginia	41.4	+ 6.0	Arvonia	81	8	Arvonia	− 6	28	1.65	−1.52	Lincoln	3.36	Danville	0.33
Washington	24.3	− 7.7	Kosmos	68	21	Twisp	−28	14	4.40	−0.13	Clearwater	16.59	Conconully	0.75
West Virginia	38.7	+ 6.4	Sutton	76	3	Cuba	−15	28	6.41	+2.92	Pickens	11.54	Lost City	2.35
Wisconsin	13.0	− 2.0	3 stations	50	18, 19	Downing Hayward	−40 −40	27 30	2.06	+0.92	Hillsboro	4.05	Antigo	0.44
Wyoming	18.2	− 1.4	Saratoga	69	6	Wells	−40	16	1.27	+0.28	South Pass City	5.30	Cheyenne (Ex. Far.)	0.05

* Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut. † 46 stations, with an average elevation of 640 feet. ‡ 140 stations.